

Bathymetry at the Vema Sill

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Abstract—The Vema Channel represents a prominent location for the northward flow of bottom water in the subtropical western South Atlantic. A recent multibeam echo-sounding survey of the Vema Sill on board F.S. *Meteor* revealed a narrow and shallow portion of the Vema Channel at 31°12'S, 39°24'W, the Vema Sill. The survey also showed the remarkably asymmetric shape of the sill region, suggesting an interaction between the bottom flow and the shape of the channel.

INTRODUCTION

INTENSIVE investigations in the subtropical South Atlantic started in late December 1990 as part of the Deep Basin Experiment (DBE), an internationally co-ordinated component of the World Ocean Circulation Experiment (WOCE). The bathymetric and hydrographic work aboard F.S. *Meteor* partly concentrated on the Vema Channel, from 30 December 1990 to 7 February 1991. Among the objectives of the DBE are: to observe and quantify the deep interior flow away from western boundary currents, to distinguish between boundary and interior mixing processes, and to understand the role of passages in the dynamics and mixing of deep water masses (WCRP12, 1988). Based on these principal DBE goals, *Meteor* cruise no. 15 included (ZENK and HOGG, 1991): the deployment of a joint German–U.S. moored current meter array between the continental slope and the western side of the Rio Grande Rise, a bathymetric survey of the Vema Channel by the Hydrosweep system of the *Meteor*, and occupation of a highly resolved CTD-section across the sill of the Vema Channel. We discuss here bathymetric observations and related hydrography concerning this prominent location for the interbasin exchange of bottom waters in the South Atlantic.

REVIEW OF THE VEMA BATHYMETRY AND TERMINOLOGY

The Deutsche Atlantische Expedition 1925–1927 investigated the physics and bathymetry of the entire South Atlantic (SPIESS, 1932). The partition of oceans into systems of basins and ridges had just been accepted, but little detail about the large-scale oceanic bathymetry was known (SUPAN, 1903).

Some of the basins could only be postulated on the basis of large-scale bottom temperature distributions (e.g. STOCKS and WÜST, 1935). The use of echo sounders on this

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initial *Meteor*-cruise resulted in a rapid increase in the number of soundings (MAURER and STOCKS, 1933). Six bathymetry charts of the South Atlantic were planned, of which five actually have been published between 1937 and 1961. The last chart no. SI₃ (STOCKS, 1937, 1961), includes the present study area. The southeastern segment of this historical map essentially summarizes all bathymetric data at the beginning of modern oceanography.

After World War II considerable efforts from many scientists, especially geologists and geophysicists from Lamont-Doherty Geological Observatory (BEHRMAN, 1969), were devoted to the exploration of the Argentine Basin, and its inlets and outlets, for near-bottom flow (EWING, 1971; LE PICHON *et al.*, 1971). One cruise, VEMA no. 22, was especially dedicated to the investigation of the bathymetry of the Vema Channel and the passage of Antarctic Bottom Water from the Argentine Basin to the Brazil Basin. More recently, significant progress in the hydrography (HOGG *et al.*, 1982) and in paleo-oceanography (JOHNSON *et al.*, 1977) on the Vema Channel has been achieved. The latter study is of particular interest because its chart served as a bathymetric basis for our cruise on the new *Meteor*. In Fig. 1, a reproduction of 1961 chart by Stocks, we have included frames representing coverage by more recently published (and unpublished) maps.

We summarize the discovery and terminology of the bathymetry at approximately 30°S, 40°W as follows. By the turn of the century, the gross bathymetry had been revealed. Due to large bottom temperature gradients from south to north near 35°S a Rio Grande Rise, dividing the Argentine Basin from the Brazil Basin, was postulated as the counterpart to the Walvis Ridge (SUPAN, 1899, 1903). Old *Meteor* Stas 43 and 44 on Profile II were coincidentally situated on opposite sides of a gap which Captain SPIESS (1932) termed the "Rio Grande Rinne". "Rinne" was later translated by LE PICHON *et al.* (1971) into "Gap". The reported depths of the two hydrographic stations were 4115 and 3385 m. Two facts are noteworthy. First, the Rio Grande Gap, 150 km in width, was recognized as a deep north-south oriented channel dividing the Rio Grande Rise to the east from the Santos Plateau to the west (HEEZEN and THARP, 1978). Second, within the gap, the old *Meteor* detected a narrow valley at sounding no. 11489, depth 4920 m, at 29°47.1'S and 39°27.5'W. The width of this cut measured less than 30 km. In the literature we found at least four different charts covering the gap between the Rio Grande Rise and the Santos Plateau (LE PICHON *et al.*, 1971; MELGUEN and THIEDE, 1974; JOHNSON *et al.*, 1977; HOGG *et al.*, 1982). Because of the intensive work done by the Lamont ship *Vema* the term "Vema Channel" first was suggested by LE PICHON *et al.* (1971) for the inner deep cut of the Rio Grande Gap.

All available bathymetric charts document a bifurcation just north of the *Meteor* Profile II (SPIESS, 1932). The 4000 m-isobath splits into an eastern and a secondary, shallower western branch, best depicted in JOHNSON *et al.*'s (1976) and HOGG *et al.*'s (1982) charts. A sill depth of 4660 m was observed at 31°12'S, 39°24'W; we call this sill the Vema Sill.

RECENT MEASUREMENTS OF THE VEMA CHANNEL

While the Vema Sill is the principal sill of the well-surveyed part of the Vema Channel, it may not be the shallowest point of the passage of bottom water from the Argentine Basin to the Brazil Basin along the Vema Channel. According to both the GEBCO (HEEZEN and THARP, 1978) and the recent South Atlantic chart (CHERKIS *et al.*, 1989), the northern end of the Rio Grande Gap between 28 and 29°S shoals to a depth shallower than 4400 m, thus isolating the deeper parts of the Vema Channel from the Brazil Basin.

On the other hand, the JOHNSON *et al.* (1976) bathymetry revised by HOGG *et al.* (1982)

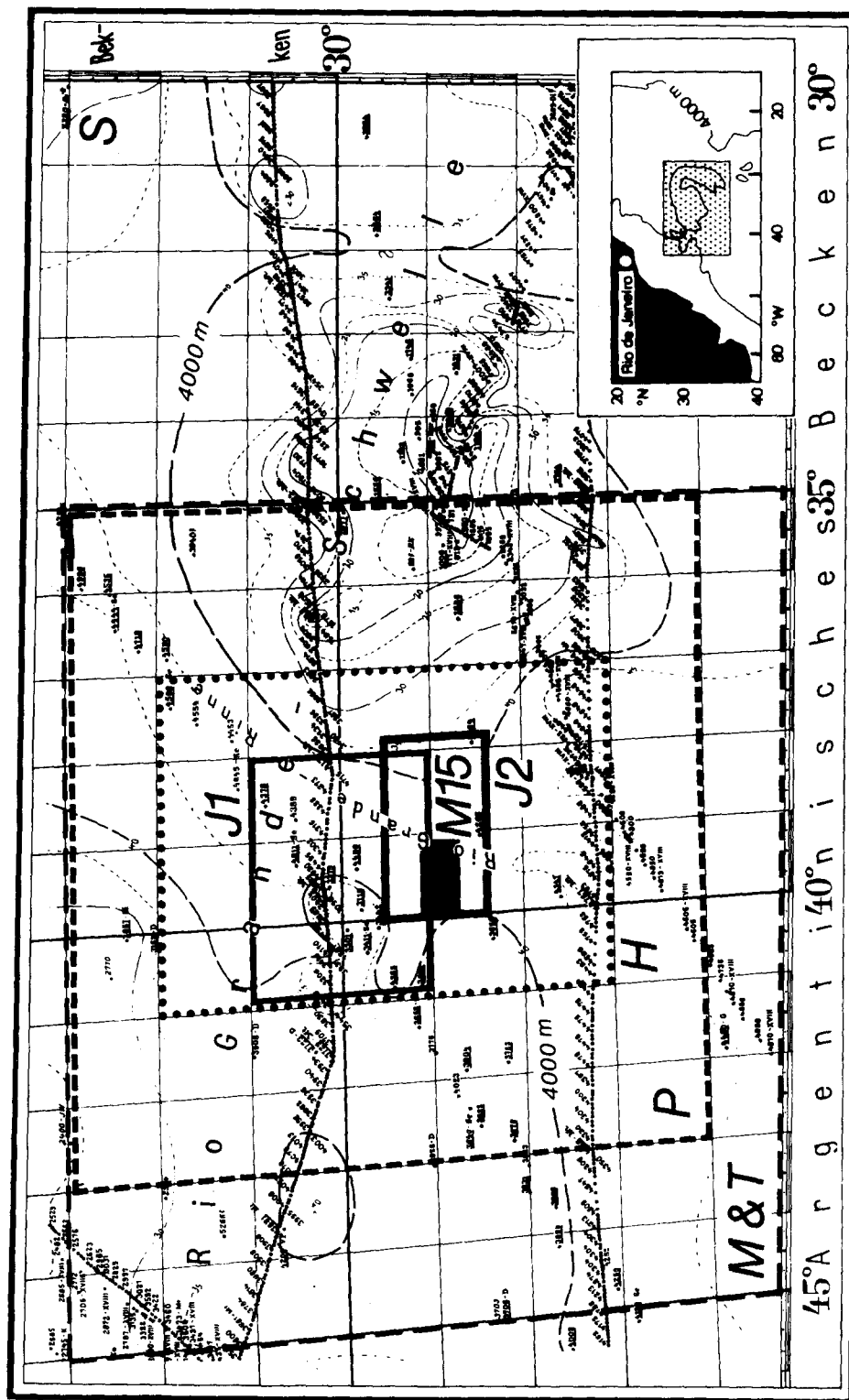


Fig. 1. Historical chart of the bathymetry of the "Rio Grande-Rinne" (Stocks, 1961). It includes all the information available in the Institut für Meereskunde, Berlin, until April 1942 and supplemented by selected additions from the German Hydrographic Institute until late 1957. The gap separates the Rio Grande Rise into an eastern and a western part. The latter today is called the Santos Plateau. A set of newer charts was published later. We have indicated the coverage of charts by LE PICHON *et al.* (1971) (P), MELGUEN and THIEDE (1974) (M), JOHNSON *et al.* (1977) (J1), and HOGG *et al.* (1982) (H). The Vema Sill was identified at 31°12'S, 39°24'W during *Meteor* cruise no. 15 in January 1991 (black box). The label (J2) marks another unpublished chart by Johnson, which was used extensively during the multibeam survey onboard F.S. *Meteor*.

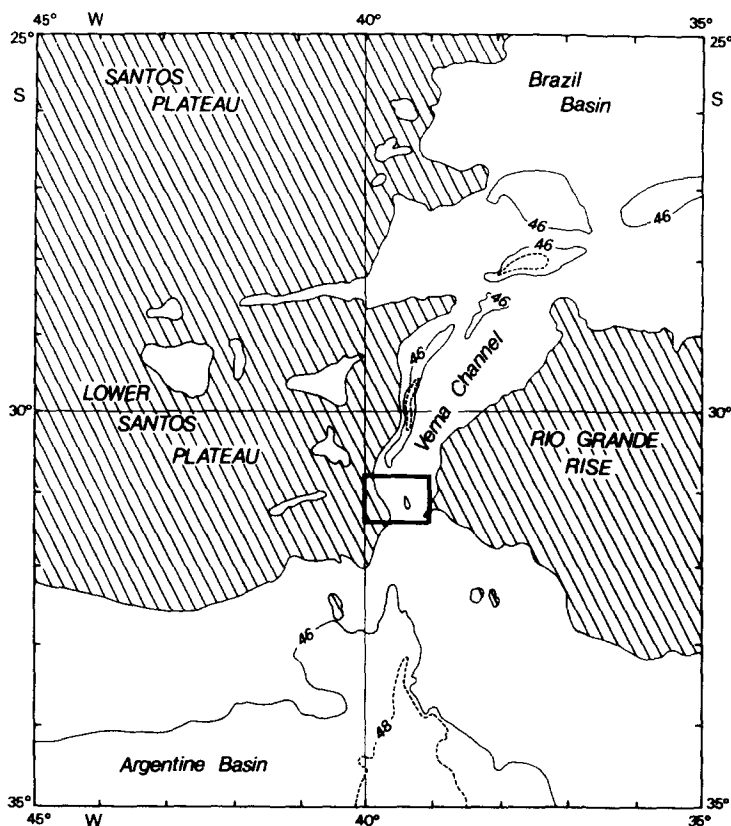


Fig. 2. Selected isobaths from CHERKIS *et al.* (1989). Depths (hundreds of meters) less than 4000 m are hatched, 4600 m (solid) and 4800 m contour (dashed). The frame at the entrance of the Vema Channel is identical with the M15-box in Fig. 1 and the location of the three-dimensional profile plot in Fig. 3.

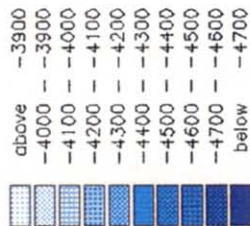
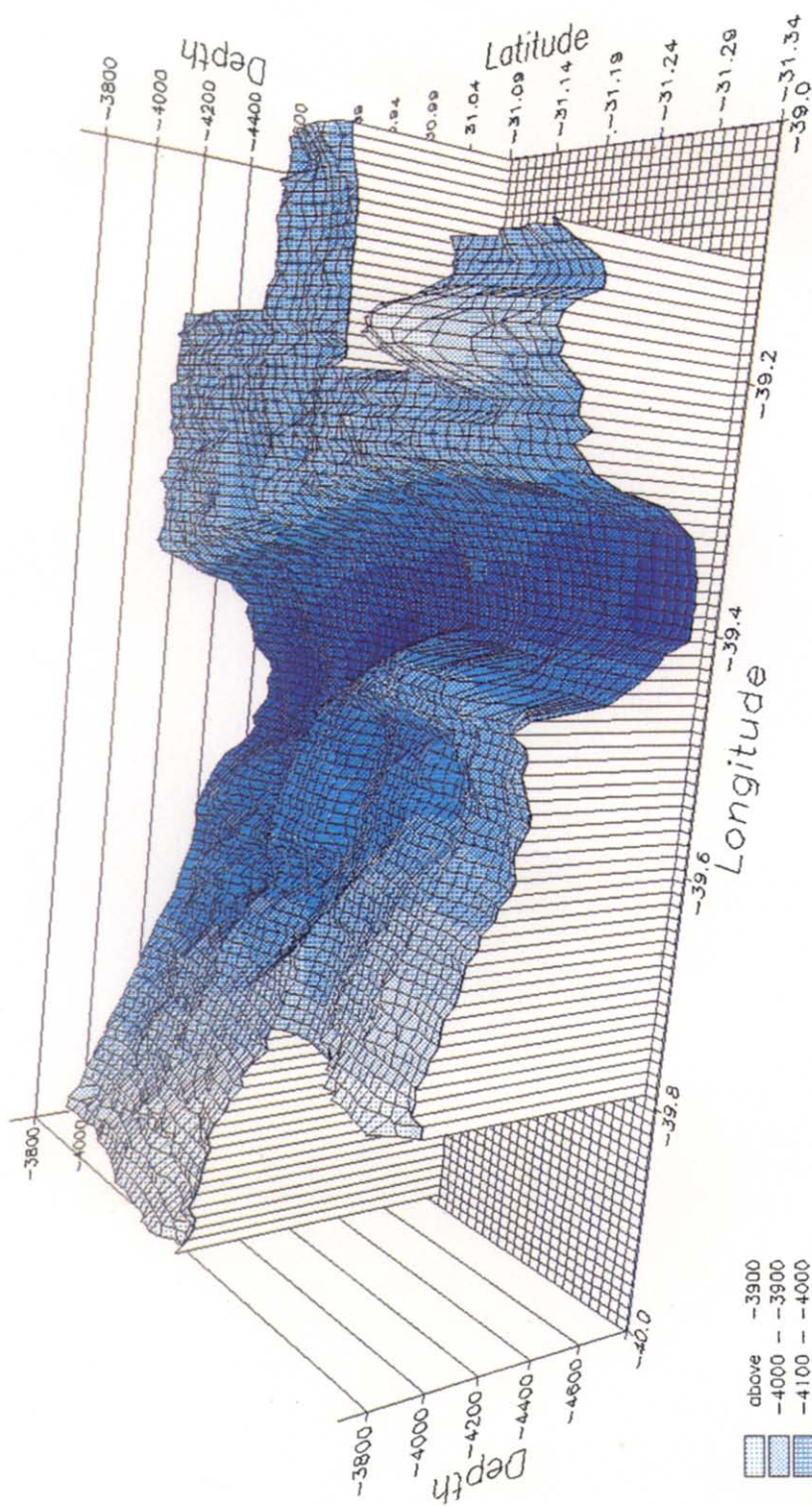
shows channel depths greater than 4700 m continuing north almost to 28°S. LE PICHON *et al.* (1971) show the northern end of the Vema Channel to be controlled at depths greater than 4570 m at 28.5°S.

A contouring scheme which opens the Vema Channel at depths greater than 4600 m between 28 and 29°S does appear to be possible, based on the reported bathymetric control of CHERKIS *et al.* (1989); nevertheless their chart would have the Vema Channel isolated at this depth somewhat farther north, near 27°S (Fig. 2). More measurements in this area are clearly needed.

BATHYMETRY OF THE VEMA SILL REGION

The Vema Sill region surveyed during *Meteor 15* is among the narrowest (maybe the narrowest) parts of the Vema Channel. The channel itself has a remarkably well defined

Fig. 3. Three-dimensional surface plot of bathymetry of the Vema Sill region, looking from south to north (downstream). The overlay contains the series of CTD stations which were used for the density section in Fig. 5.



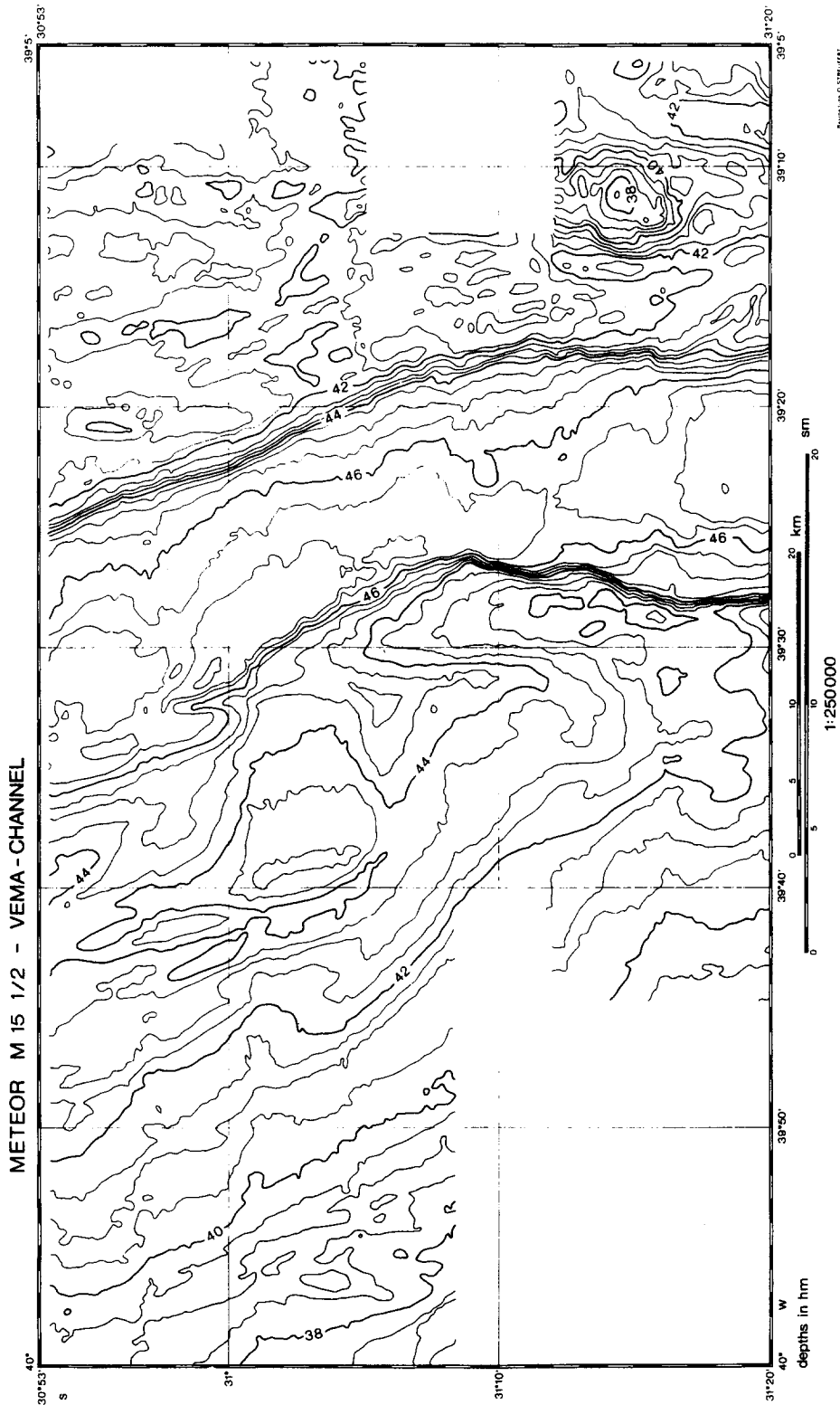


Fig. 4. Bathymetry of Vema Sill region from multibeam survey. Contour interval is 50 m.

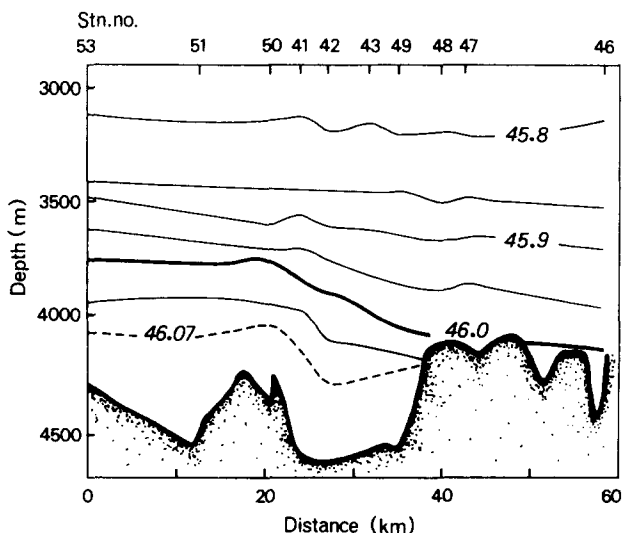


Fig. 5. Density anomaly (kg m^{-3}) referred to 4000 dbar across the Vema Sill. The tendency of the flow to follow isobaths is indicated by the doming of isopycnals near km 20.

form, shown most clearly by a three-dimensional surface plot (Fig. 3). On either side are relatively flat areas which have been called the eastern and western terraces (JOHNSON *et al.*, 1976).

The bathymetry obtained from the multibeam survey (HYDROSWEEP) shows the exact location of the Vema Sill at $31^{\circ}12'S$, $39^{\circ}24'W$, and also the surrounding topography (Fig. 4). The western terrace shoals from 4600 m to less than 3800 m, and is marked by an apparent meander of the channel, which more or less loses its western wall north of $31^{\circ}05'S$. The existence of a true meander of the flow was confirmed by a CTD survey, which showed that the flow follows isobaths to some extent, turning west and south and then back to the north again (Fig. 5 and see, for example, the 4400 m isobath, Fig. 4). This valley was not shown on any of the bathymetric studies, although a similar feature was shown just to the north of our survey zone by JOHNSON *et al.* (1976). Judging from the many stations occupied downstream (HOGG *et al.*, 1982), however, this valley does not serve as a significant alternative pathway for bottom water.

A fundamental question that surveys such as this one may help to answer is the nature of the interaction between bathymetry and flow. To what extent is the shape of the channel controlled by flow? The fact that the earth's rotation induces a stronger flow on the western side of the channel may affect the overall shape and meandering through a stronger erosion on this side. An alternative reason for the existence of the western valley could be given by the relationship between this bathymetric feature and the location of the sill itself. Reverse circulations are common in hydraulic solutions downstream of the control sill (HOGG, 1983).

Presently we do not know if the Coriolis force, a hydraulic effect, or random variations in currents and seafloor structures are more important in generating features such as the unnamed valley described above. Nevertheless, there is a clear tendency for the western wall of the Vema Channel to meander, in contrast to the relatively straight eastern side.

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